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ATLANTIC TROPICAL DISTURBANCES OF 1968

R. H. SIMPSON, NEIL FRANK, DAVID SHIDELER, and H. M. JOHNSON

National Hurricane Center, Weather Bureau, ESSA, Miami, Fla.

1. INTRODUCTION

This is the second of an annual series of reports on Atlantic tropical disturbances prepared by the National Hurricane Center (NHC), Miami, Fla. Simpson et al. (1968) defined the tropical models used by the National Hurricane Center. These models and definitions continue to apply and will not be restated here. The primary goal and emphasis in the NHC analyses are the detection and tracking of the antecedent conditions, or seedling disturbances, from which hurricanes and severe storms grow. In the absence of conventional data from the tropical oceans the meteorological satellite has been the primary tool of detection and for tracking the significant migratory rain disturbances and distinguishing them from minor or transitory convective systems. It has become the means of "separating the wheat from the chaff" and significantly has shown that often the most innocuous-appearing cloud systems in a satellite mosaic may be the most important ones from the viewpoint of severe storm development. Nevertheless, the progress in understanding of the structure and dynamics of these seedlings will continue to be slow until the satellite observations can be supplemented by some direct probing of the circulation which bears the disturbed weather. This year the first research aircraft flight[1] was made across the tropical Atlantic to investigate disturbances that were under satellite surveillance. It is hoped that this program can be extended and expanded in the next few years, to enhance the value of satellite observations.

In the absence of detailed synoptic circulation data, one must look to some form of dynamic climatology to gain a clearer understanding of the circulation instabilities which set the stage for the intensification of the disturbances. The NHC is striving to develop such a climatology of disturbances and will report the important results in this annual series of articles.

2. CENSUS OF 1968 TROPICAL SYSTEMS

The year 1968 was an illustrious one for tropical disturbances for two reasons. First, there appears ~~to~~ have been an abnormally large number of waves and other disturbances. While an accurate climatology of tropical disturbances has not been possible in the past, some forecasters who have given professional attention to this problem for several decades indicate there seem to have been more waves in the easterlies this season than in any previous year since the 1940's.[2] Secondly, in spite of the abundance of disturbances, 1968 was a minimal year for hurricane activity in the Atlantic. A discussion of the 1968 hurricane season by Sugg and Hebert (1969) appears in another article in this issue.

Table 1 shows that there were 110 tropical systems in 1968, from which evolved 22 depressions and seven tropical storms. Four of the storms became hurricanes. Fifty-seven of the 110 systems were tropical waves and ITC disturbances whose origin was in Africa. Twenty-five disturbances first appeared as a part of the intertropical confluence (ITC). This census does not include many sprawling, elongated, weak and transitory convective areas associated with the ITC or those of subsynoptic scale, but is confined to those of discrete and persistent dimensions, usually 100–300 n.mi. in diameter, with apparently intense convection.

Figures 1–3 and table 1 summarize the tropical systems of 1968. Table 1 shows the number of systems which formed within various geographical areas. This information is displayed graphically in figure 1. Figure 2 shows the tracks of depressions and certain disturbances. Disturbances that remained a part of the intertropical confluence are not included since experience has shown that these do not develop until or unless they break away and become imbedded in the trade winds. Nevertheless, they are reflected in the census summary of figure 1. A tropical disturbance has been defined (Simpson et al., 1968) as a migratory tropical convective system, which nominally brings rain to a synoptic-scale area 100–300 mi in diameter and which has been tracked for at least 24 hr. It is the classification of tropical weather systems that includes in ascending order of intensity the tropical depression, tropical storm, and hurricane. While these criteria are

TABLE 1.—*The number of tropical systems which formed in various geographical areas in 1968 (upper troposphere cold Lows not included)*

System type	AREAS OF FORMATION: Africa	Tropical Atlantic	Subtropical Atlantic	Caribbean	Gulf	Total independent systems
1 Waves	39	18	0	0	0	57
2 ITC disturbance	17	1		7		25
3 Disturbance (other)	0		6	5	0	11
4 Depressions	1	(4)	9 (1)	4	3	17 (5)
5 Named Storms	0	(1)	(3)	(2)	(1)	0 (7)
Total						110

Numbers in parentheses indicate those systems which were counted in a weaker stage.

[1] ESSA's Research Flight Facility conducted this flight on behalf of the National Hurricane Center under the direction of the Environmental Research Laboratory.

[2] Private communication from Dunn (1969).

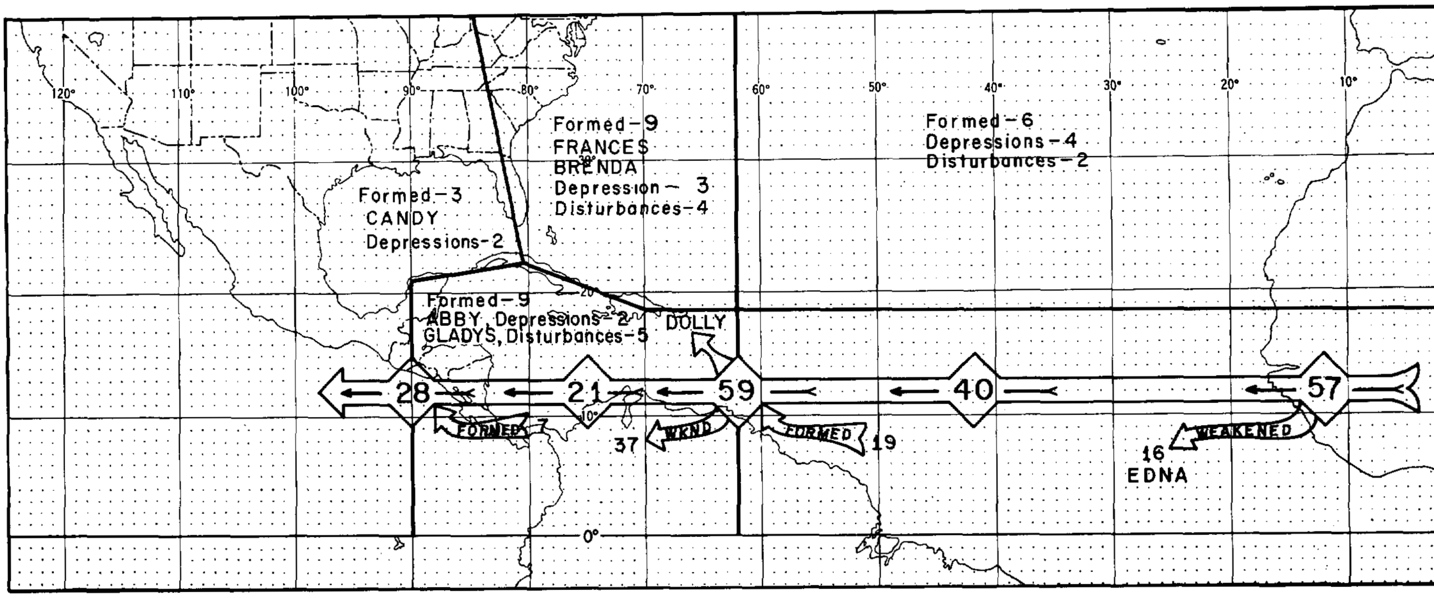


FIGURE 1.—Summary of the synoptic-scale tropical systems observed from western Africa to the eastern Pacific during the hurricane season June–November 1968. The number of systems passing five areas, the West Coast of Africa, the mid-Atlantic Ocean, the Lesser Antilles the Caribbean, and the Far Eastern Pacific Ocean, are indicated by the large numerals. The line along 18.5°N separates low-latitude Tropics from high-latitude Tropics and subtropics (see text).

used operationally at the National Hurricane Center, this census, in an attempt to eliminate the more transitory systems, counted only those disturbances which could be identified on at least three successive satellite mosaics (a 48-hr period).

Figure 3 presents graphically the record of the tropical systems which emerged from Africa or evolved over the tropical Atlantic. It includes a time cross-section for Dakar including the 700-mb geopotential for Dakar, and a similar time cross-section for Barbados. The wind shifts associated with the passage of waves are shown at the standard levels. The vertical length of the trough lines corresponds to the depth of the layer influenced by the waves.

The agreement between the 700-mb geopotential minima and the wind shift line of these waves is good except at Dakar in June and October. During June and October the upper troposphere flow here was westerly and dominated by a persistent trough. Carlson (1969*a*) found similar substantial responses in the surface pressure to the passage of tropical waves.

At Dakar the first wave of the season occurred on June 12 and the last on October 20. Easterly wave activity over western Africa reaches a maximum in the months from July through September. This is precisely the period of time when the upper tropospheric easterly jet was well established. When in October the high-level flow reversed, wave activity ceased.

Figure 4 shows the history of three disturbances which formed over subtropical portions of the western Atlantic in early July 1968. Disturbance A, with a large, bright, almost circular cloud system near 30°N and 65°W on July 4, was one of the more deceptive disturbances viewed in 1968. It apparently formed in situ, and the initial mosaic indicated considerable organization of convective cells suggesting the possibility that a storm might be developing. However, the data show that the surface pressure under this cloud was 1023 mb, and there was no evidence of cyclonic flow in the lower tropospheric wind field, nor was there evidence of a cold Low in the upper troposphere.

Two other disturbances are shown in figure 4. Disturbance B developed southeast of Disturbance A on the 5th, and Disturbance C formed within a weak stationary trough which had persisted off the southeast U.S. coast for several days.

A typical movement of an ITC disturbance in the Atlantic is shown in figure 5. This system appeared near the West Africa coast on August 19. The small, bright cloud mass can be followed easily across the Atlantic in this figure.

Of the 57 tropical systems which emanated from Africa (fig. 1), 40 maintained their identity as far west as the Lesser Antilles. Of the 40, 29 were tropical waves of the "inverted V" type, and 11 were disturbances on the ITC. Nineteen others, first detected over the tropical Atlantic, also migrated as far west as Barbados so that a total of 59 systems moved into the Caribbean from the open Atlantic. It is remarkable (and we believe characteristic) that less than half the wave disturbances which moved into the Caribbean survived the transit of this sea. There is a rationale which may be cited in support of this observation. First, the midlatitude westerlies intrude into the Caribbean and displace or reduce the depth of the easterlies more frequently than in the tropical Atlantic east of the Caribbean. Secondly, the upper tropospheric trough which extends in a narrow zone southwestward from temperate latitudes into the central Caribbean, appears to serve as a damper on convective systems approaching from the east. Experience has repeatedly shown this to be true in the case of tropical cyclones. This may be due to pronounced advection of

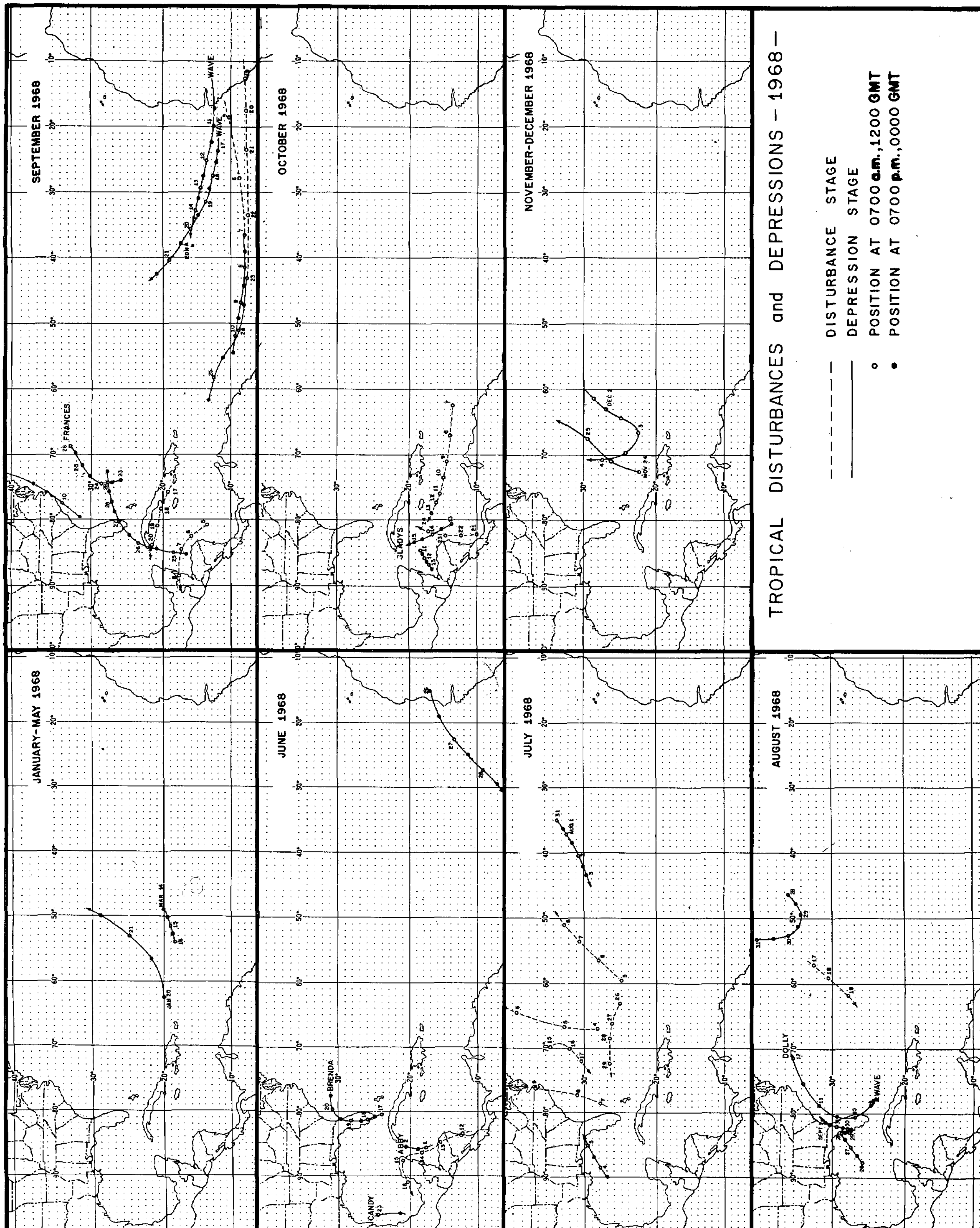


FIGURE 2.—Tracks of all tropical depressions and of the tropical disturbances that originated away from the ITC during 1968 over the North Atlantic Ocean.

shear vorticity in the high troposphere which inhibits the divergent outflow of these systems. "Seedling" disturbances even in the absence of an orgainzed outflow are apparently subdued similarly by a high troposphere trough or shear line.

The 21 wave disturbances which survived the trek across the Caribbean were joined by seven others which formed in the Caribbean (mainly in the western portion) with the result that a total of 28 Atlantic disturbances extended their influence across Central America into the eastern Pacific where a number of them triggered the formation of eastern Pacific hurricanes.

The average westward speed of the 40 systems which originated in Africa was 15.5 kt; the range was 8.5 to 25.0 kt. The average speed of the waves was somewhat faster than that of the ITC disturbances (16 kt and 14 kt, respectively).

Nine depressions formed over subtropical portions of the north Atlantic. Two of these intensified and became named storms (Brenda and Frances). Two others nearly became tropical storms (see Sugg and Hebert, 1969). One formed off the South Carolina coast on September 9, moved northward skirting eastern North Carolina, and crossed Long Island during the predawn hours of the 11th. It had a central pressure slightly below 1000 mb and winds to gale force. The other near miss was initiated over the southeastern Bahama Islands on November 24. This depression raced rapidly northeastward, but was completely engulfed by a tremendous baroclinic development as it approached Bermuda on the 25th.

3. COMPARING 1967 AND 1968

Two procedural changes in 1968 make it difficult to compare the census for 1968 with that of 1967.

The 1967 survey was confined to wave disturbances for which there was supporting evidence in the circulation. ITC disturbances were not counted unless they broke away and became trade wind eddies. In 1968 all disturbances that met the criteria given by the definition stated earlier were tracked. Also in 1967 the Antilles time cross-section was based on data from Antigua and Guadeloupe, both stations north of 16°N. However, in 1968 Barbados (13°N) was used so that possibly more low-latitude disturbances were recorded.

Excluding cold Lows, a total of 54 tropical systems were identified in 1967. In 1968, 110 systems were recorded. This total includes 11 subtropical disturbances and five ITC disturbances which would not have been considered in 1967. However, after deleting these, a total of 94 systems were identified in 1968 compared to 54 in 1967. Table 2 compares the number of depressions and the wave disturbances emerging from Africa in 1968 with those of 1967, by months. The numbers in parentheses indicate ITC disturbances which passed south of Dakar and would not have been included in 1967. Every month in 1968 had more disturbances moving out of Africa than in 1967.

In sharp contrast, table 2 shows a significant decrease in the number of depressions in 1968. This is particularly true if the off-season depressions are not considered in 1968. A significant difference concerns the strength of the African systems during August, normally the time of maximum activity for east Atlantic and African disturbances. In 1967, seven systems emerged from Africa. All were of depression strength, while not one of the 1968 African systems was as strong.

4. THE LARGE CIRCULATION ENVIRONMENT

Normal circulation data for the tropical and equatorial Atlantic are difficult to apply, first because the paucity and irregularity of observations in this area yield a nonhomogeneous record and large probable errors in the normals. Secondly, gradients of pressure, temperature, and wind within the trades are generally small, so that small deviation errors may lead to large errors when one interprets the impact of deviations (from normal) on the circulation. However, as we have seen in 1968 there were significantly more disturbances than in 1967, and it is interesting and useful to compare the mean circulations for these 2 yr. For purposes of this discussion we shall consider the month of August in which the greatest difference in numbers of disturbances occurred. On a planetary scale, figure 6 shows the differences in geopotential (1968–1967) at 700 mb. While in tropical latitudes the geopotential was a bit higher in 1968 than in 1967, in temperate latitudes there was a decidedly lower geopotential in 1968 than in 1967. This reflects the fact that storm tracks over the central Atlantic moved at a lower latitude in 1968 than in 1967 and implies the possible intrusion of baroclinic conditions into lower latitudes in 1968.

Figure 7 allows comparison of the surface circulations for August 1967 and 1968 and figure 8 that at 200 mb. In August 1967 the lower troposphere circulation was more vigorous and the easterlies extended through a greater depth than in 1968. In the upper troposphere the semi-permanent trough extending southwestward from north of the Azores to Puerto Rico was more persistent in 1967 than in 1968, but was significantly farther south in 1968 than in 1967. While a comparison of these circulation features does not provide explicit answers to the differences observed in disturbance activity, it is apparent that the occurrence of tropical disturbances or, as we prefer to call them, "hurricane seedlings," does not correlate positively with the depth of the easterlies or the strength and persistence of the trade winds.

On the other hand, a relatively low base of westerlies during 1968, and the presence of large vertical shear may have exercised a substantial constraint to the development of disturbances. In general the large vertical shear of the horizontal wind, according to Gray (1968), is unfavorable for the development of hurricanes because of the inability of organized rain storms to compact the latent heat released into a relatively small deep column (100–300 mi

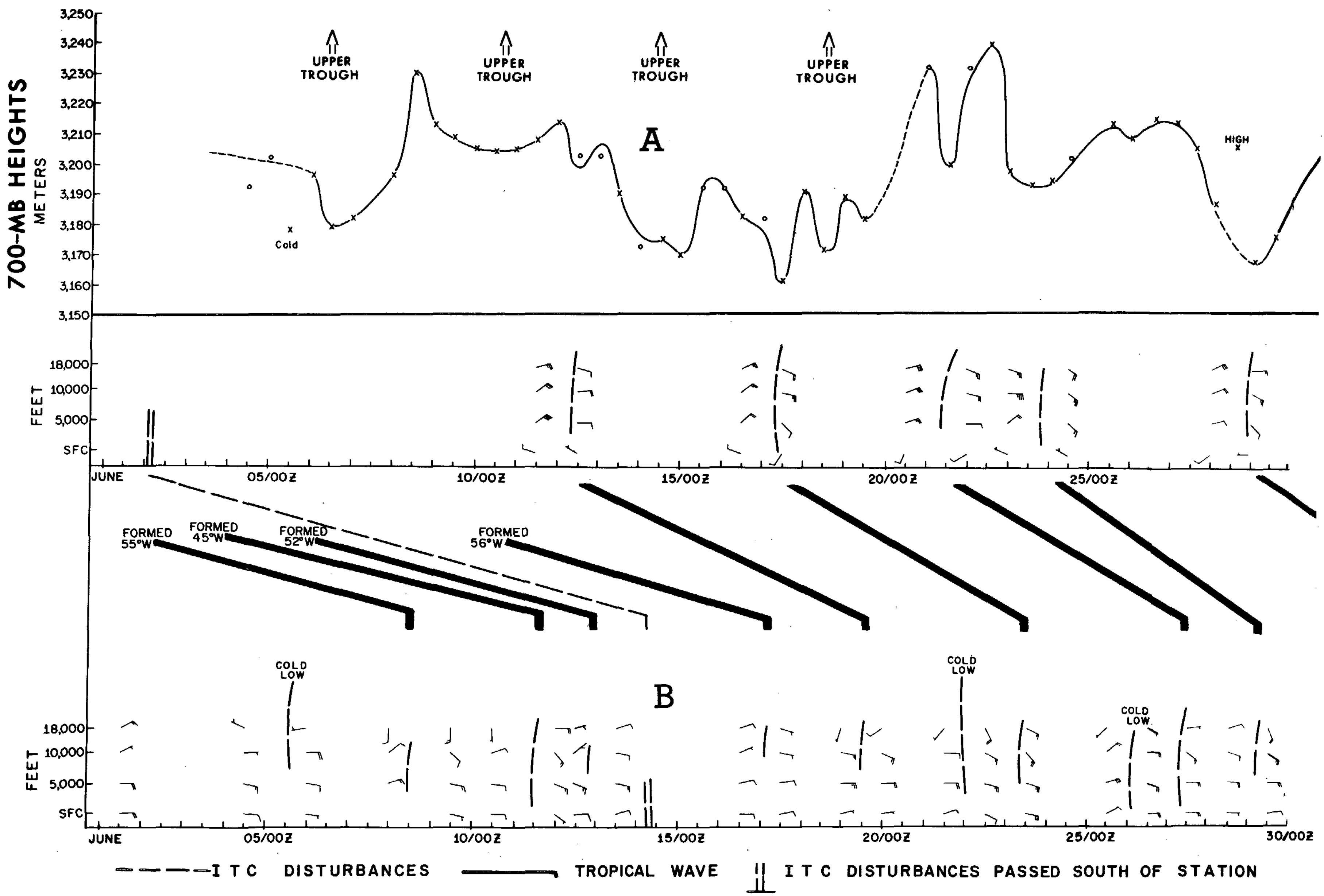
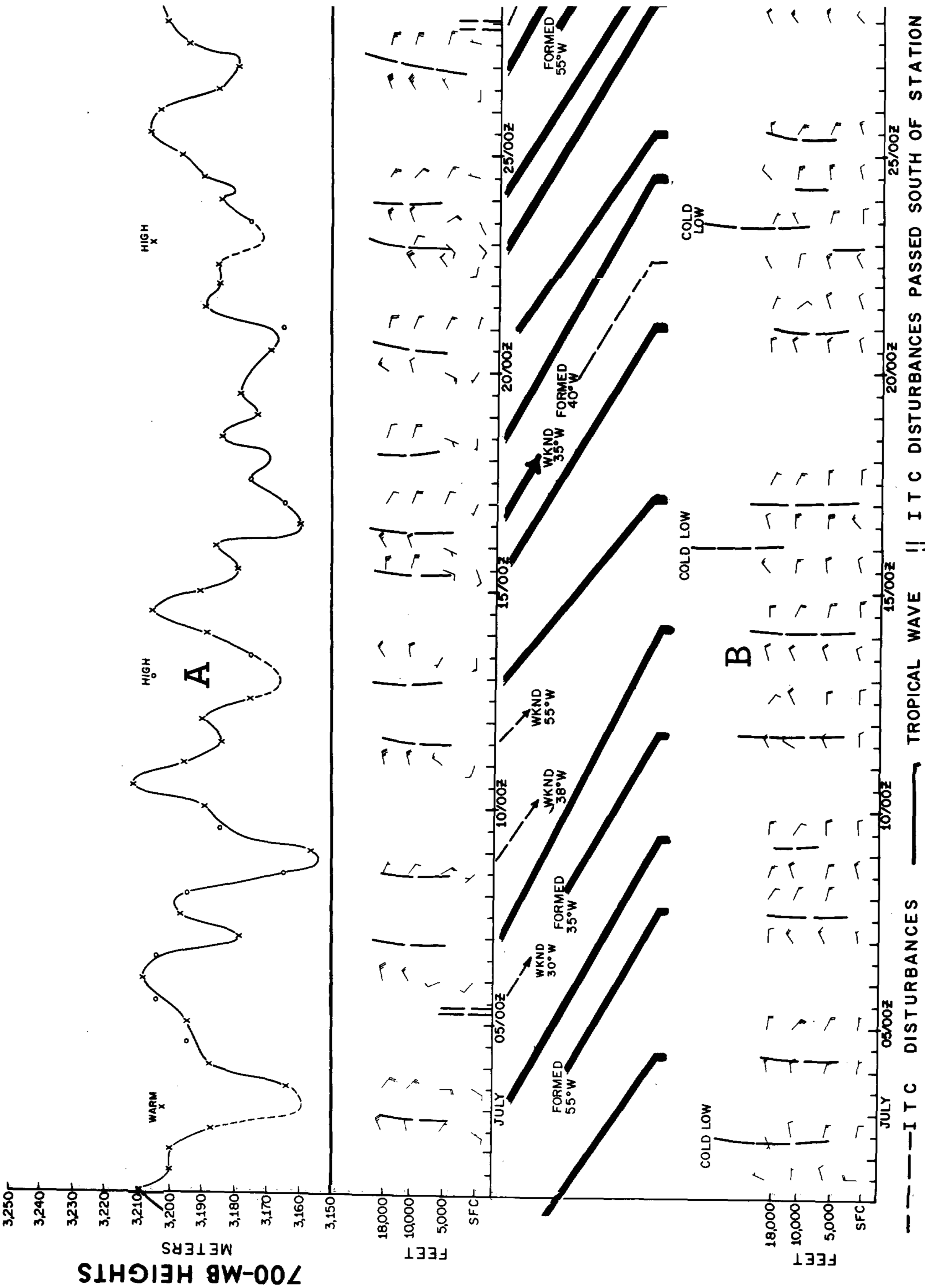


FIGURE 3.—Time cross-sections for Dakar (A) and Barbados (B) for the period June 1 to Oct. 30, 1968. Wave axes are indicated by dashed lines. Solid bars connect times when a given wave passed first Dakar and then Barbados; thin dashed lines do the same for ITC disturbances. The continuous time-series curve presents the Dakar 700-mb geopotential height variation. Upper trough positions are indicated by arrowheads (see text). Some of the 700-mb height values were considered to be in error. These have been indicated by *high*, *low*, *cold*, and *warm*.



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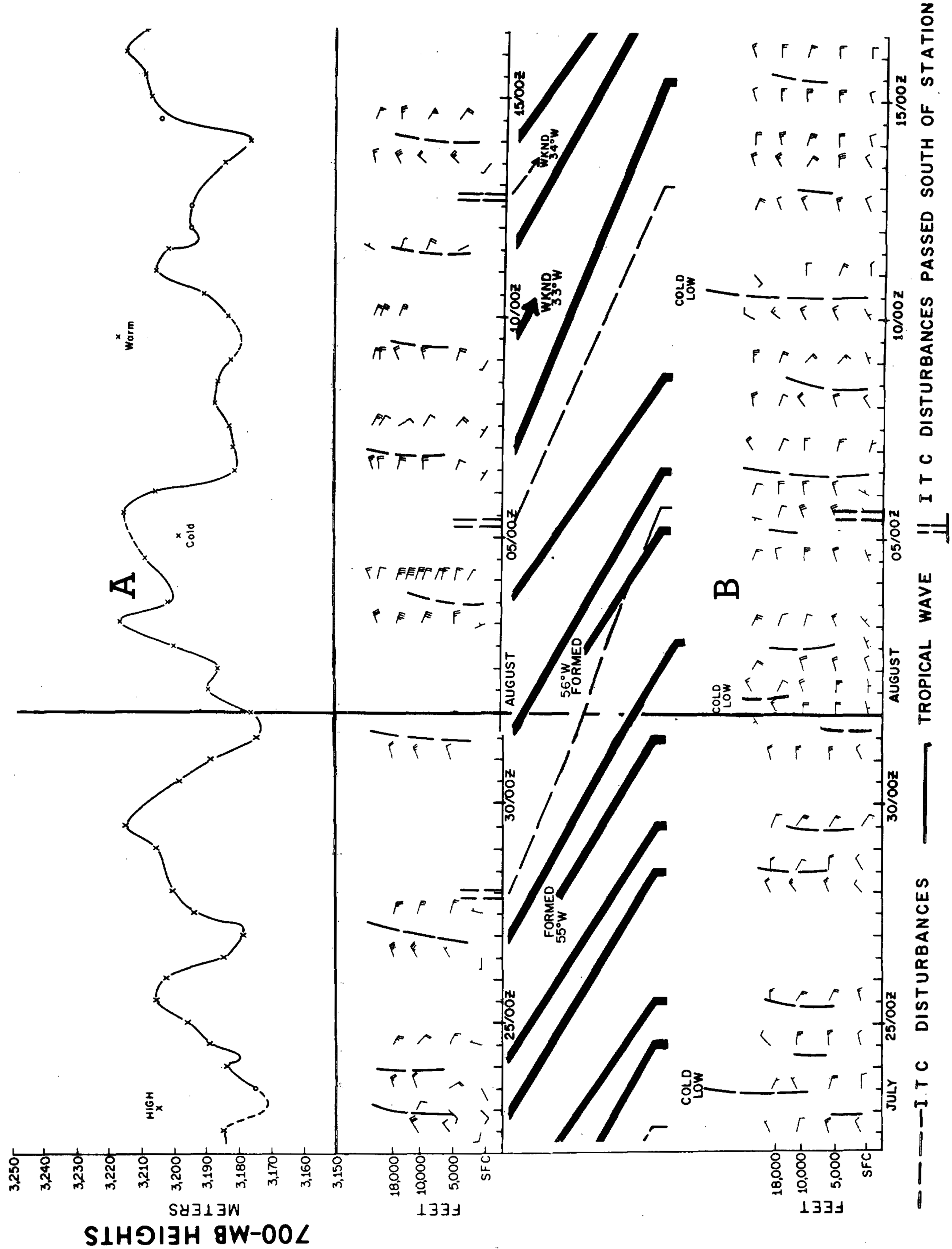

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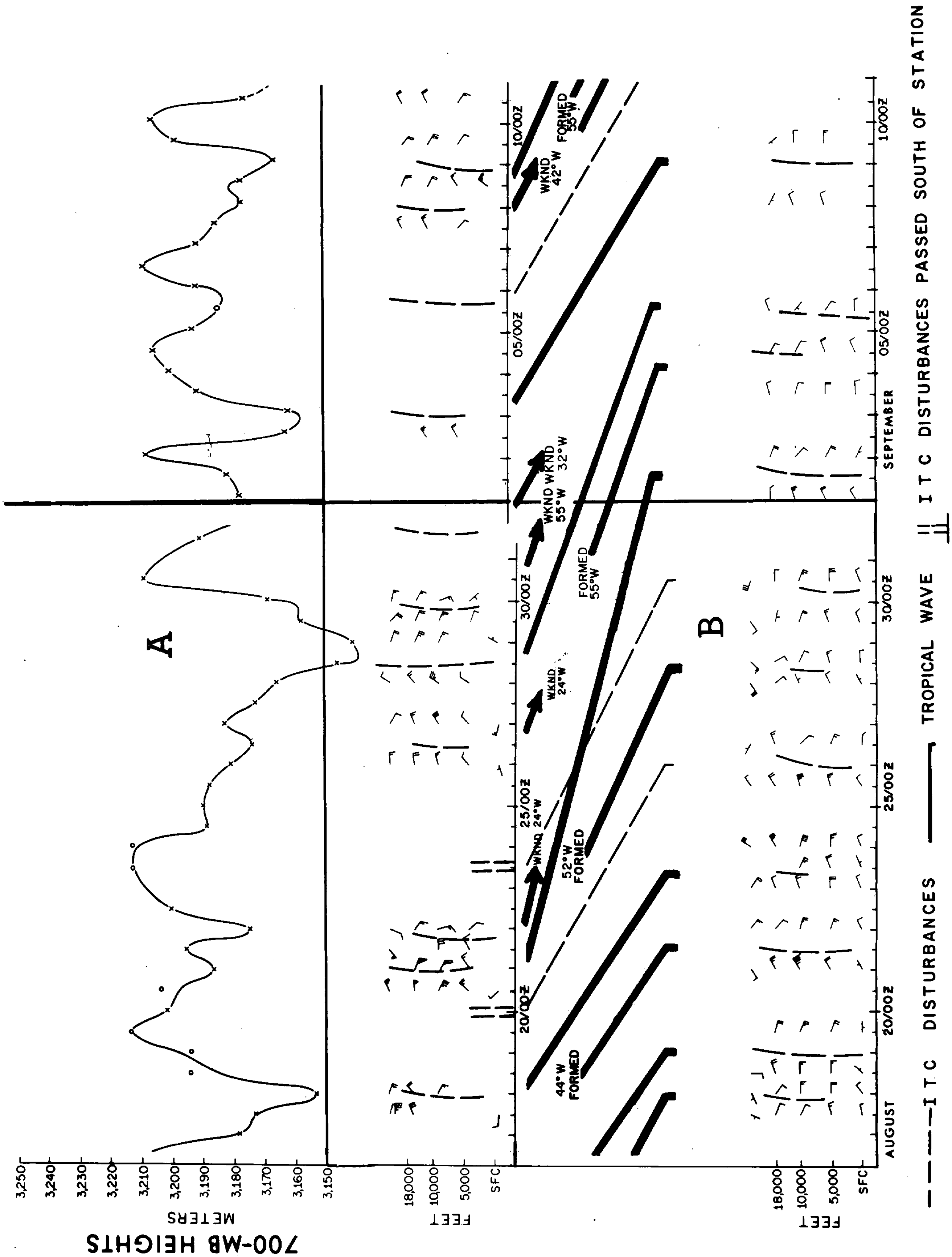

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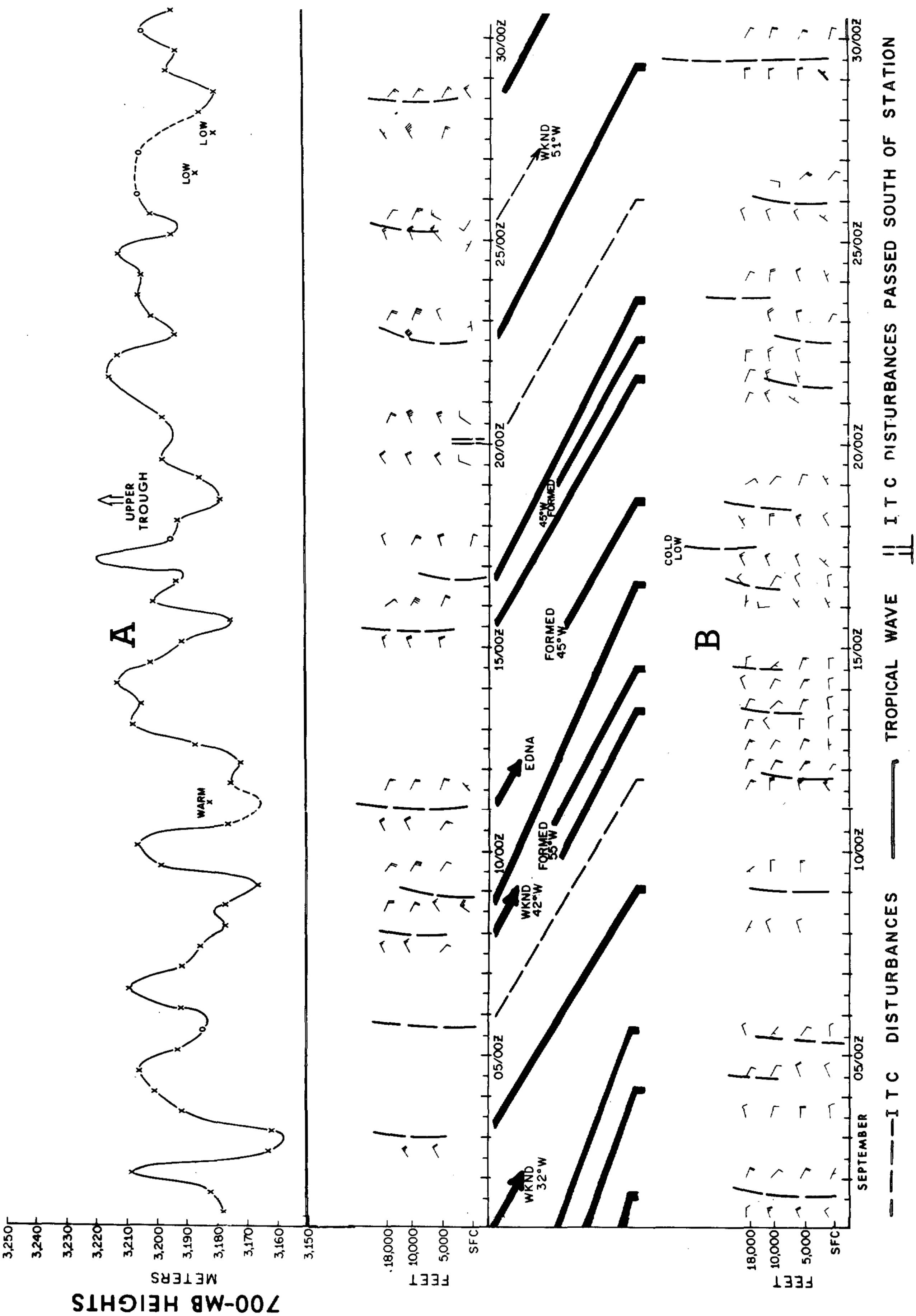

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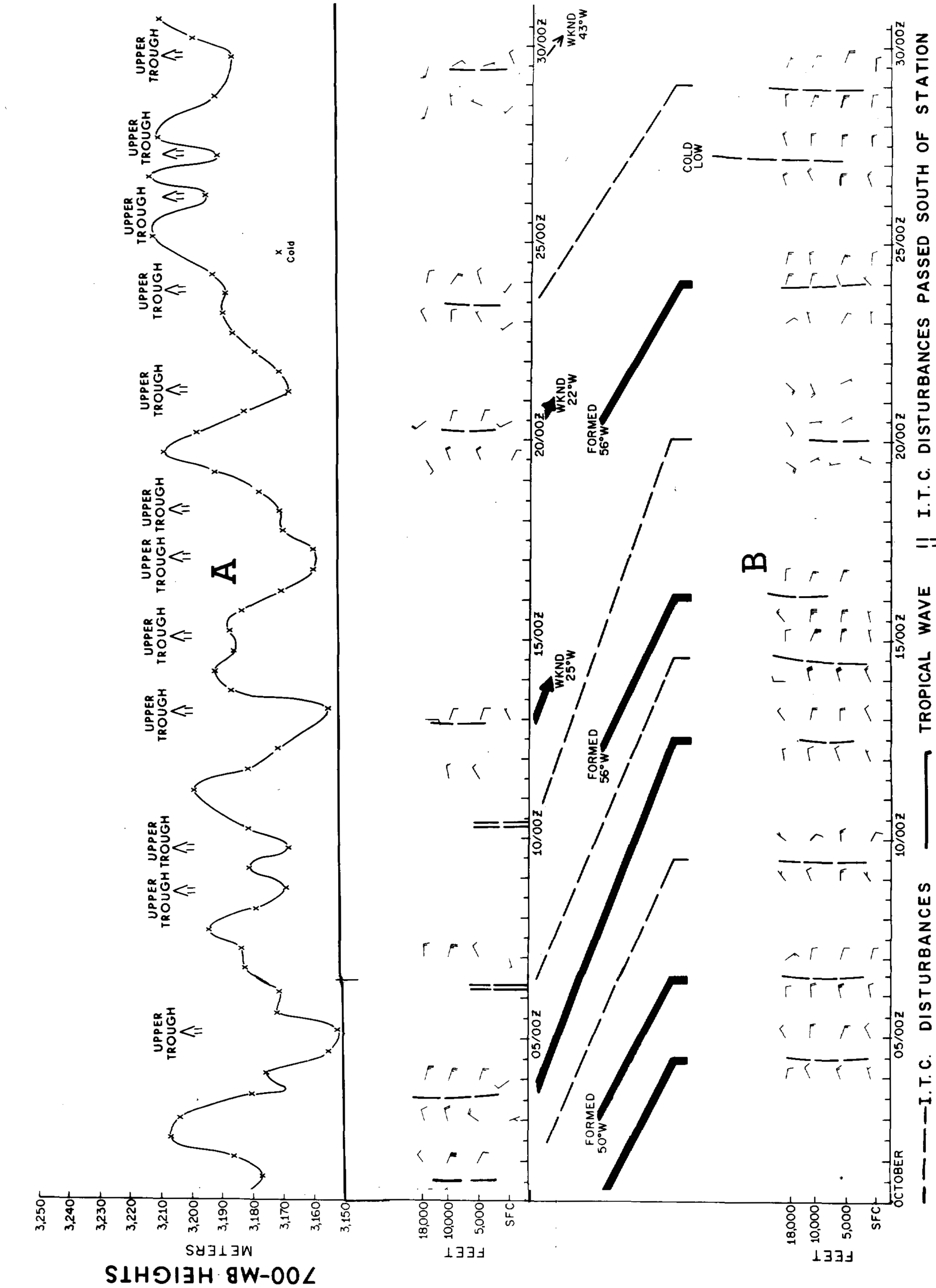

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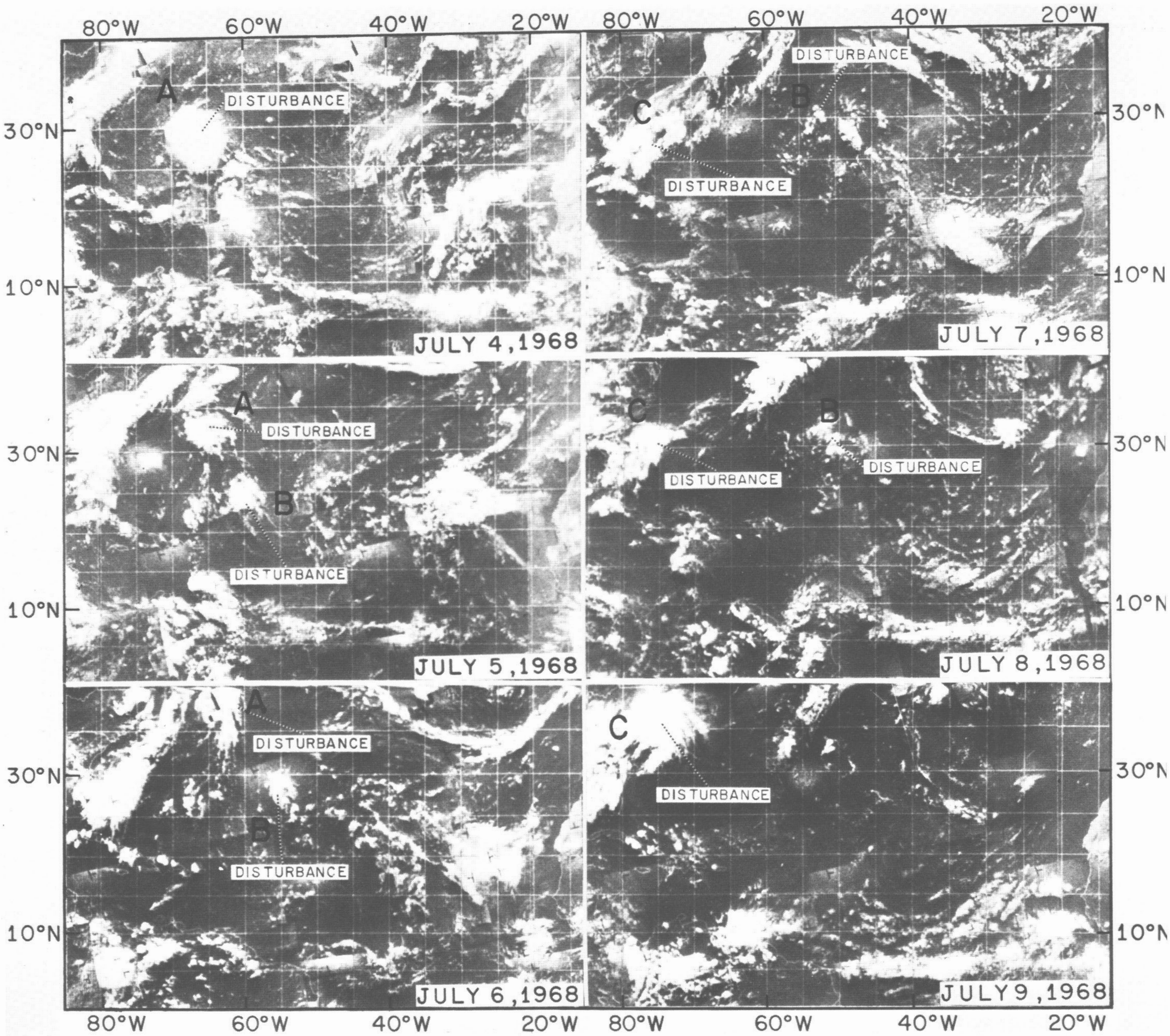

FIGURE 4.—A series of six digitized mosaics for early July showing three tropical disturbances that formed over subtropical areas of the North Atlantic. Disturbance A, near 30°N, 65°W, on July 4, is depicted three times; Disturbance B, near 25°N, 60°W, on July 5, is shown four times; and Disturbance C, near 30°N, 75°W, on July 8, is shown three times.

wide) of the troposphere where the resulting pressure falls would significantly increase pressure gradients. It is appropriate to comment that the daily tropospheric mean shear chart[3] used in hurricane predictions at the National Hurricane Center during the 1968 hurricane season was most effective in delineating days in which cyclogenesis was favorable. Cyclogenesis during the 1968 season occurred in locations where the troposphere mean wind shear was less than 10 kt.

It is generally recognized that disturbances in the Tropics develop into hurricanes only when certain conditions exist (even though these conditions may not be sufficient for formation). The most important of these are 1) the presence of deep easterlies, 2) the presence of a forcing mechanism for mass transport into the depression in the friction layer, 3) minimum vertical shear of the horizontal wind, and 4) at the storm periphery, the presence of a high tropospheric current which systematically conducts the heat away from the storm center to a colder environment. (See e.g., Dunn, 1960; Riehl, 1954; Simpson, 1967.) In August 1968 it appears that the main conditions not met were 2) and 3). Westerly shear pervaded the areas of potential development most of the month.

5. THE ATLANTIC AS A SOURCE OF EAST PACIFIC HURRICANES

Many of the disturbances from Africa and the eastern Atlantic moved into the Caribbean Sea without development; but when they extended their influence across

[3] The tropospheric mean shear is obtained by subtracting the pressure weighted mean wind for the layer 1000–600 mb from that of the layer 600–200 mb.

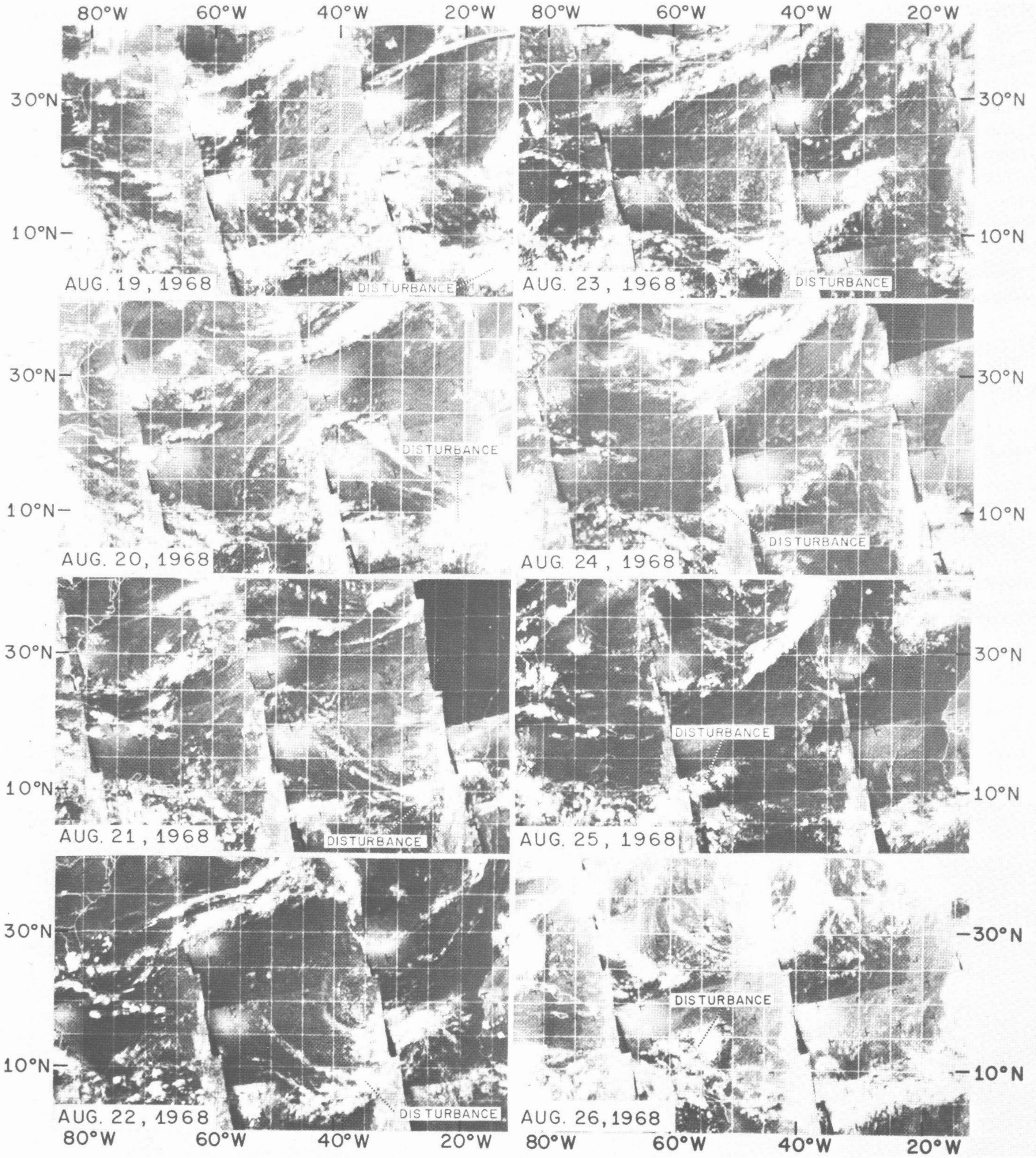

FIGURE 5.—A series of eight digitized mosaics for the period Aug. 19–26, 1968, showing the westward progress of a typical relatively strong ITC disturbance. A well-marked African tropical wave is shown near 20°N, 30°W, on August 19 and can be followed easily for 4 more days.

Central America into the Pacific, they found a more hospitable environment for development, mainly one of lower vertical wind shear. At least four of the 19 tropical storms which formed in the eastern Pacific were triggered from disturbances which had their origins in Africa or the Atlantic.

The Pacific west of Nicaragua and Costa Rica is a fertile genetical region for tropical storms mainly because of the persistence of small vertical shear, of cyclonic vorticity, and of low-level convergence associated with the ITC in this area. While many tropical storms in this region form within this envelope of favorable conditions, it seems clear that the impulse which initiates cyclogenesis frequently comes from migratory Atlantic disturbances. Because of the paucity of upper air information and the changes which occur in cloud patterns as wave systems cross the mountains of Central America, it is difficult to establish with certainty in all instances the exact role played by the Atlantic disturbances in triggering east Pacific cyclogenesis; but the evidence is that the role is significant.

6. STRUCTURE OF AFRICAN WAVES

The structure and sources of energy which drive the African waves or inverted V's remain obscure. However, some insight into their structure can be gleaned from vertical time cross-sections from the few sounding stations in the path of these systems. Figure 9 contains a panel of three satellite pictures showing the progress of a complex wave system which left Dakar on July 22 and arrived at Barbados on July 28. These panels are flanked by time cross-sections of the wind and temperature anomaly. These anomalies are based upon monthly means at Barbados and Dakar, respectively. The satellite mosaics reveal a rather extensive synoptic-scale organization extending from 5°–25°N lat., spreading over a longitude interval of at least 30°. Several times in 1968, two wind shifts were experienced at Dakar within a span of 24 to 36 hr. This could be either two waves, or one system with a complex structure. We favor the latter alternative. In either case a dual wind shift was conserved in a number of systems tracked from Africa to the Lesser Antilles. The double structure could also be observed in the cloud pattern. When the wave passed Dakar, figure 9, the principal windshift line was the western axis about which a closed circulation appeared to exist in the lower 5,000 ft. The eastern axis was more pronounced at higher levels. At Barbados, however, the wave amplitude of the western axis was greatest in the middle troposphere and of the eastern axis the lower troposphere. In both instances the largest falls in D-values occurred with the eastern axis. The largest temperature anomaly was the positive area in the upper troposphere which at Dakar occurred upstream from the eastern axis, but at Barbados had grown in size and dominated the area between the two axes. The colder temperatures in low levels at Dakar and absent at Barbados were probably a result of the combination of cold

TABLE 2.—*Monthly comparisons of tropical systems between 1967 and 1968*

	Depressions		Dakar waves	
	1967	1968	1967	1968
Jan.-May		2		
June	4	4	6	7 (1)
July	2	2	8	15 (1)
Aug.	7	3	7	16 (4)
Sept.	6	7	6	11 (1)
Oct.	10	2	3	8 (3)
Nov.-Dec.	0	2		
Total	29	22	30	57 (10)

Numbers in parentheses indicate ITC disturbances which passed south of Dakar and would not have been considered in 1967.

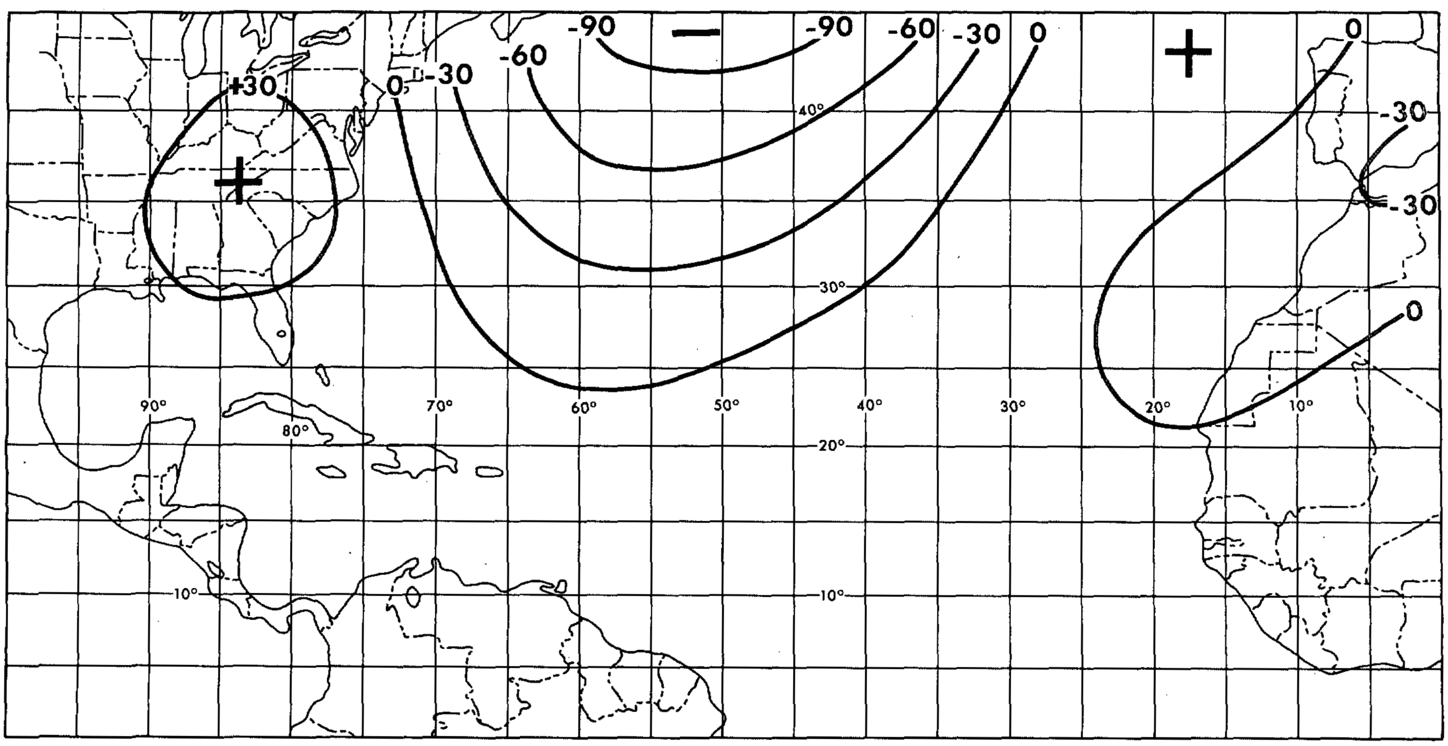

FIGURE 6.—The difference in the August 700-mb geopotential heights (meters) from 1967 to 1968.

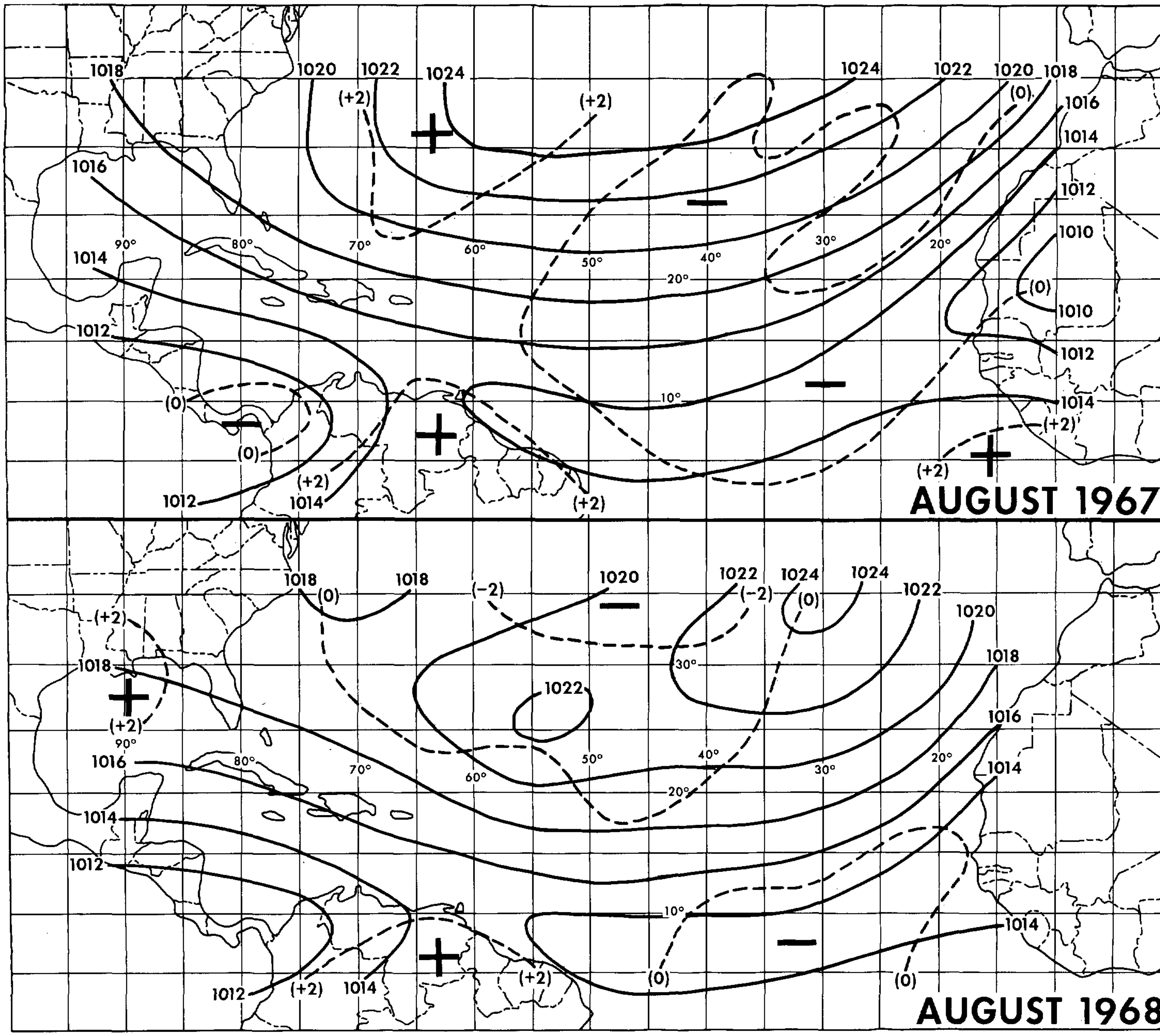

FIGURE 7.—The mean August sea-level pressures for 1967 and 1968 and departures from normal.

water and low-level convergence at Dakar. While the positive anomalies in the upper troposphere may reflect the accumulation of latent heat from organized convective cells, there is essentially no measurable horizontal temperature gradient in the active (large amplitude) levels of the wave disturbance.

7. CONCLUDING REMARKS

One hundred ten tropical systems were detected and followed over the tropical North Atlantic, Caribbean Sea, and the Gulf of Mexico during 1968. Like 1967, more than half originated over Africa. A more detailed analysis of circulations associated with the systems as they crossed Africa was made daily by Carlson (1969*a*, *b*). Approximately two-thirds of the African systems maintained their identity as far west as the Antilles, and nearly half of these continued westward across the Caribbean and into the Pacific where some appeared to have triggered tropical storms.

There were significantly more seedling disturbances in 1968 than in 1967. Yet, in sharp contrast, a much lower percentage of the systems developed into named storms. The primary difference seems to have been attributable to two factors. First, there was a persistence of large vertical shear of the horizontal wind in genetical regions. Secondly, the systems which formed initially over Africa were weaker when they reached the Atlantic in 1968 than in 1967. In 1967 nearly all the systems which moved off Africa were initially, or soon became, depressions.

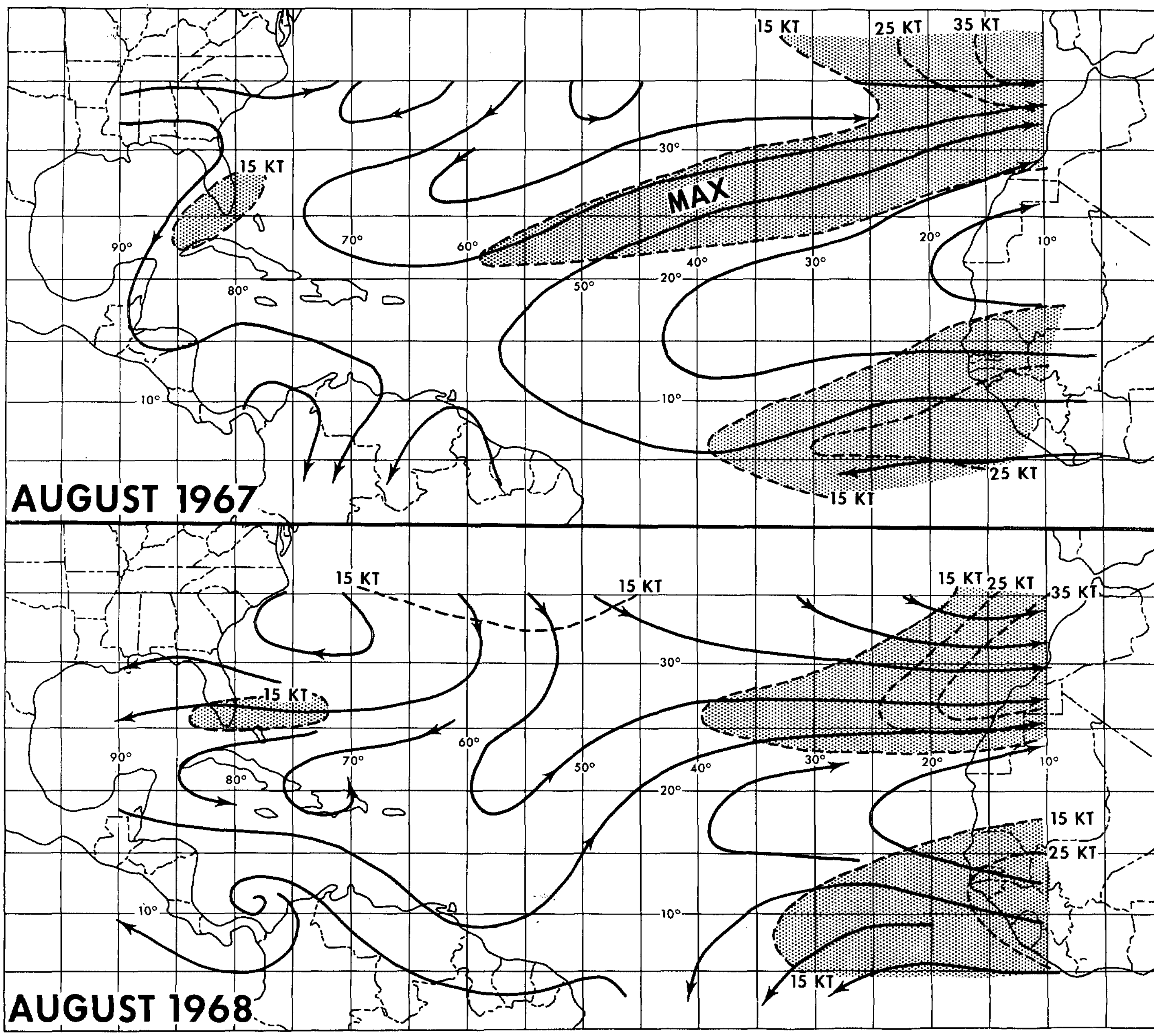

FIGURE 8.—The mean August 200-mb streamline-isotach charts for 1967 and 1968. Shaded areas represent regions of wind speeds greater than 15 kt.

This was undoubtedly related to large-scale circulation differences. In 1968, the flow pattern over the subtropical central North Atlantic was influenced greatly by several dramatic baroclinic developments in August and September. The negative anomalies dictated by the lower latitude tracks of temperate latitude storms produce unfavorable conditions for tropical storm development.

Finally, it appears that the occurrence of tropical waves does not correlate positively with geopotential anomalies over the midlatitudes of the central Atlantic Ocean. This differs from the findings of Landers (1963) who reported that the initiation of easterly waves seems to be associated with surges of below-normal pressure in temperate latitudes, which result in stronger pressure gradients in the Tropics.

On one occasion in 1968 the ESSA's Research Flight Facility made a long reconnaissance mission from Barbados to Dakar and return in support of the National Hurricane Center. This flight had the primary objective to investigate two disturbances. Unfortunately, one of the systems weakened rapidly and the length of the flight prohibited diverting to make a detailed investigation of the other one. The energetic nature and the structure of these disturbances will probably remain uncertain until a more complete investigation can be made with aircraft in conjunction with satellite observations.

It is apparent that the maximum amplitude of these wave disturbances occurs in the layer between 5,000 and 15,000 ft. The horizontal temperature gradients across the waves are very small, and no conclusion can yet be drawn as to whether these systems are warm or cold core.

ACKNOWLEDGMENTS

Appreciation is expressed to Dr. J. Kuettner, Director of Special

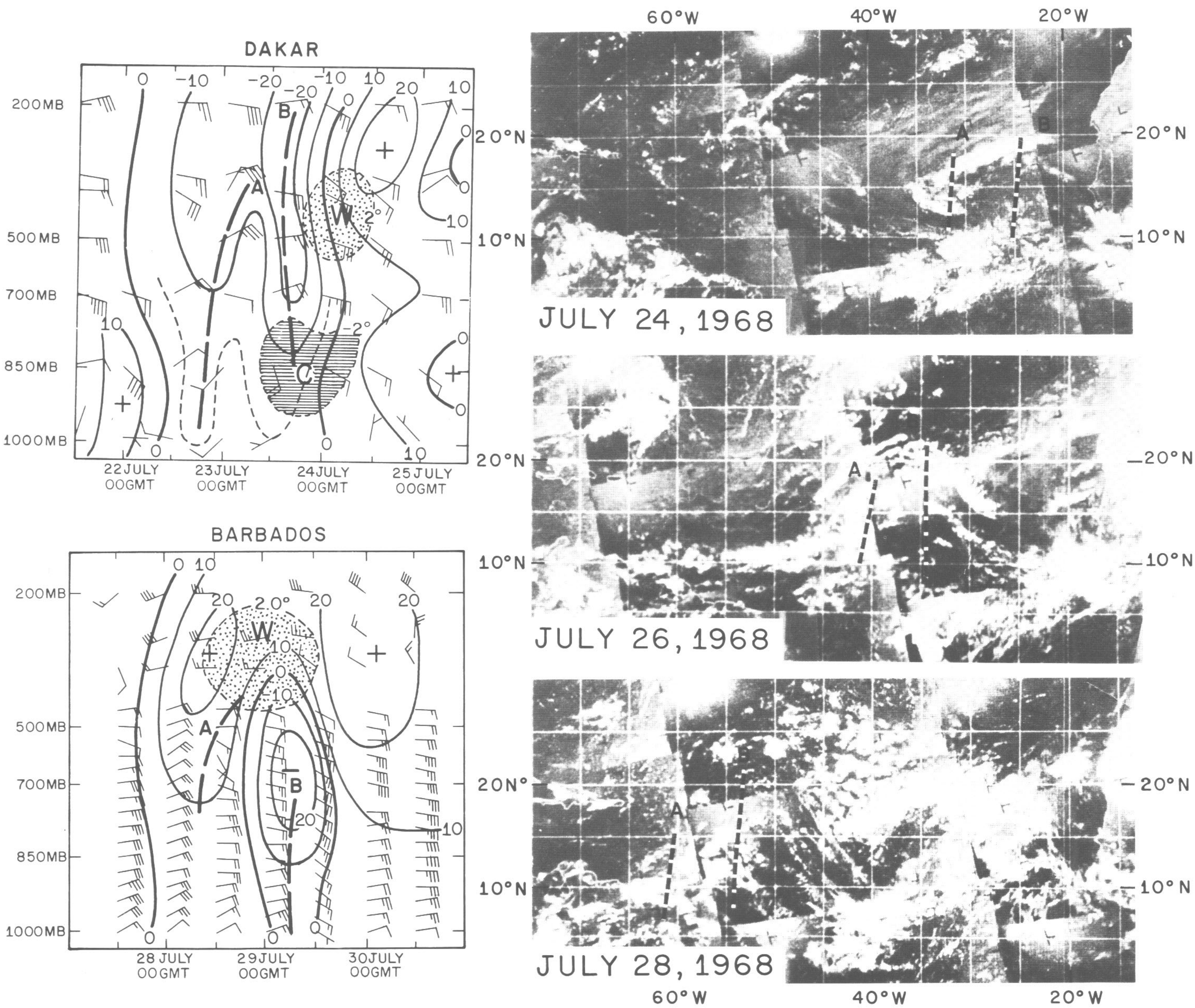

FIGURE 9.—Satellite pictures and time cross-sections for Dakar and Barbados showing the structure of a tropical wave which crossed the Atlantic in late July 1968. The solid lines are height departures (meters) from mean monthly values. Shaded or stippled areas represent temperature anomalies greater than 2° K.

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